

Numerical study about the natural and induced heat convection on far-field groundwater flow.

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In the safety assessment of nuclear waste disposal, the influences of heat convection on far-field groundwater flows cannot be neglected. These influences should be estimated by conducting detailed thermal-hydrological (TH) numerical analysis at the site characterization stage. However, as a first step, it is worthwhile to estimate the influence of heat convection using only the thermodynamic parameters and the geological model obtained in the early stage of site characterization.

In this study, the thermal-hydrological coupled simulation code TOUGH2 was applied to a homogenous and heterogeneous models with vertical highly permeable zone. The homogeneous model was used to estimate the influence of permeability on the natural groundwater flow caused by the surface topography, and the heterogeneous models were used to estimate the influence of permeability, heat flow from the bottom, and the thickness of the highly permeable zone on the local onset of natural convection. From the results of numerical simulations, we extracted path lengths and travel times along stream traces representing regional groundwater flow and compare them to uncoupled models that assume the temperature distribution is fixed. Two dimensionless numbers (Peclet number and Rayleigh number) were derived to analyze the results of sensitivity studies. The following are the main results of this study.

1. In the homogeneous case, comparing the results of the TH coupled model to the uncoupled model, when the Peclet number is less than 0.2, the error of the average velocity along the stream traces in the uncoupled model is less than 10%.
2. The ratio of the average velocity along the stream traces between the coupled model and the uncoupled model increases with an increase of the Peclet number until the Peclet number is 2.0. When the Peclet number exceeds 2.0, the ratio of the average velocity becomes smaller and close to 1.0.
3. In the inhomogeneous model with a vertical highly permeable zone, the critical Rayleigh number and the critical temperature gradient for the onset of natural convection were estimated from the analytical solution of heat convection considering the aspect ratio of a convection cell. In this case, as the cell height increases, the critical temperature gradient decreases, and a small convection cell is generated in the highly permeable zone. As the result, the influence on the stream trace in the natural groundwater flow system is small.
4. In the inhomogeneous model with a vertical highly permeable zone with a low permeability core, the critical Rayleigh number and the critical temperature gradient can be estimated by approximating the local heterogeneity as a permeability anisotropy. In this case, the existence of a low permeability core prevents the formation of a small convection cell, and the height of the convection cell becomes larger than in the vertical highly permeable zone case. As the result, the stream traces can be discharged in the highly permeable zone in the middle of the model with thermodynamic parameters that do not cause the discharge in highly permeable zone in other cases.